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(54) **TWO-SPEED TRANSMISSION FOR ELECTRIC VEHICLES**

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*F16H 2200/0034* (2013.01)

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See application file for complete search history.

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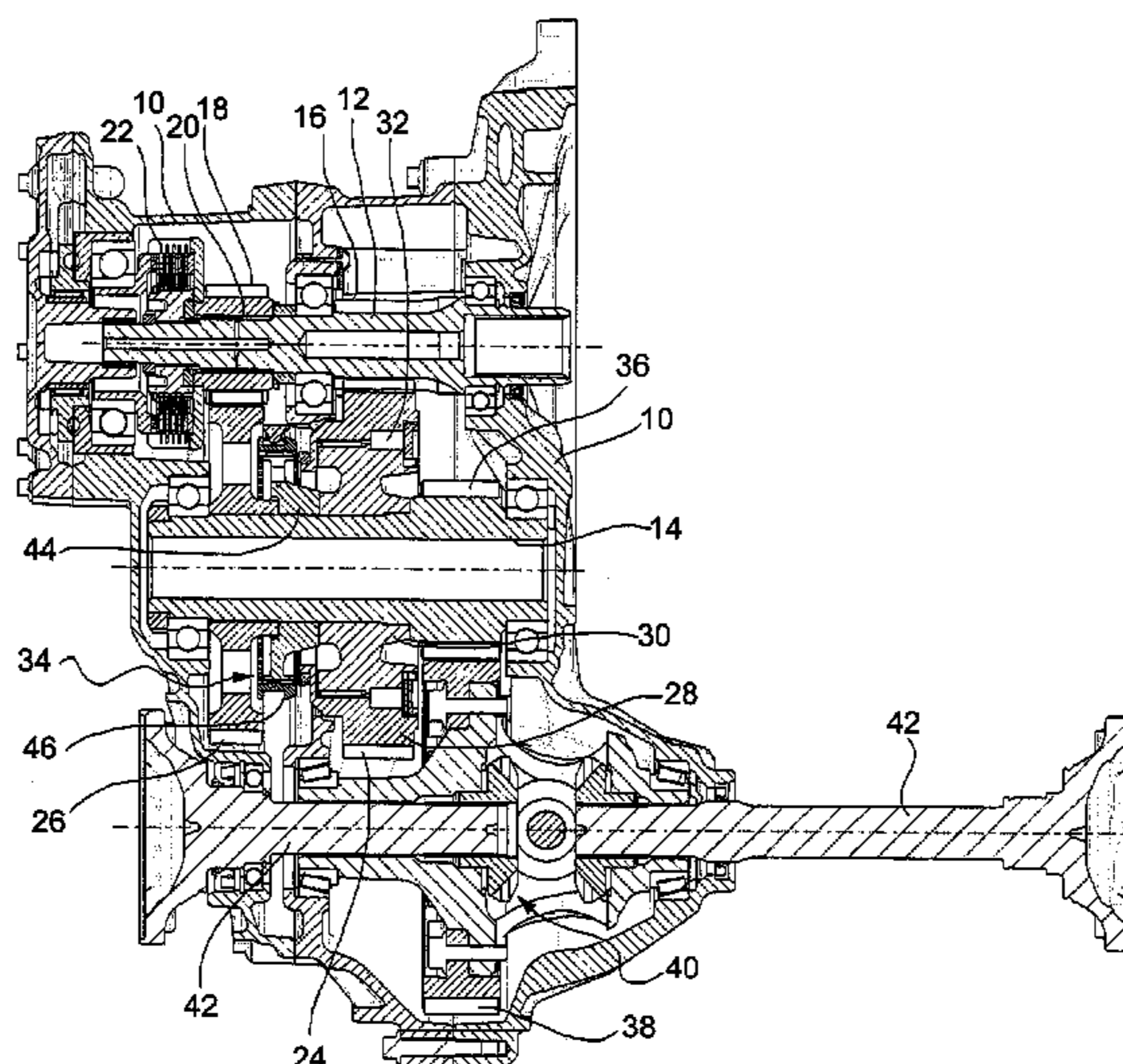
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(57) **ABSTRACT**

The transmission comprises: a primary shaft; a secondary shaft; a gearing of first speed comprising a first driving gearwheel carried by the primary shaft and a first driven gearwheel carried by the secondary shaft and permanently meshing with the first driving gearwheel; a gearing of second speed comprising a second driving gearwheel carried by the primary shaft and a second driven gearwheel carried by the secondary shaft and permanently meshing with the second driving gearwheel; an overrunning clutch associated to one of the first driving gearwheel and first driven gearwheel to allow the transmission of the torque via the gearing of first speed only in the direction from the primary shaft to the secondary shaft; a first coupling device arranged to connect either of the first driving gearwheel and first driven gearwheel, namely the gearwheel to which the overrunning clutch is associated, for rotation directly with the respective shaft, so as to allow the transmission of the torque via the gearing of first speed also in the direction from the secondary shaft to the primary shaft; and a second coupling device arranged to connect either of the second driving gearwheel and second driven gearwheel for rotation with the respective shaft. The first and second coupling devices are both shiftable between an open condition and a closed condition independently of each other. The first coupling device is normally open, whereas the second coupling device is normally closed.

**9 Claims, 3 Drawing Sheets**



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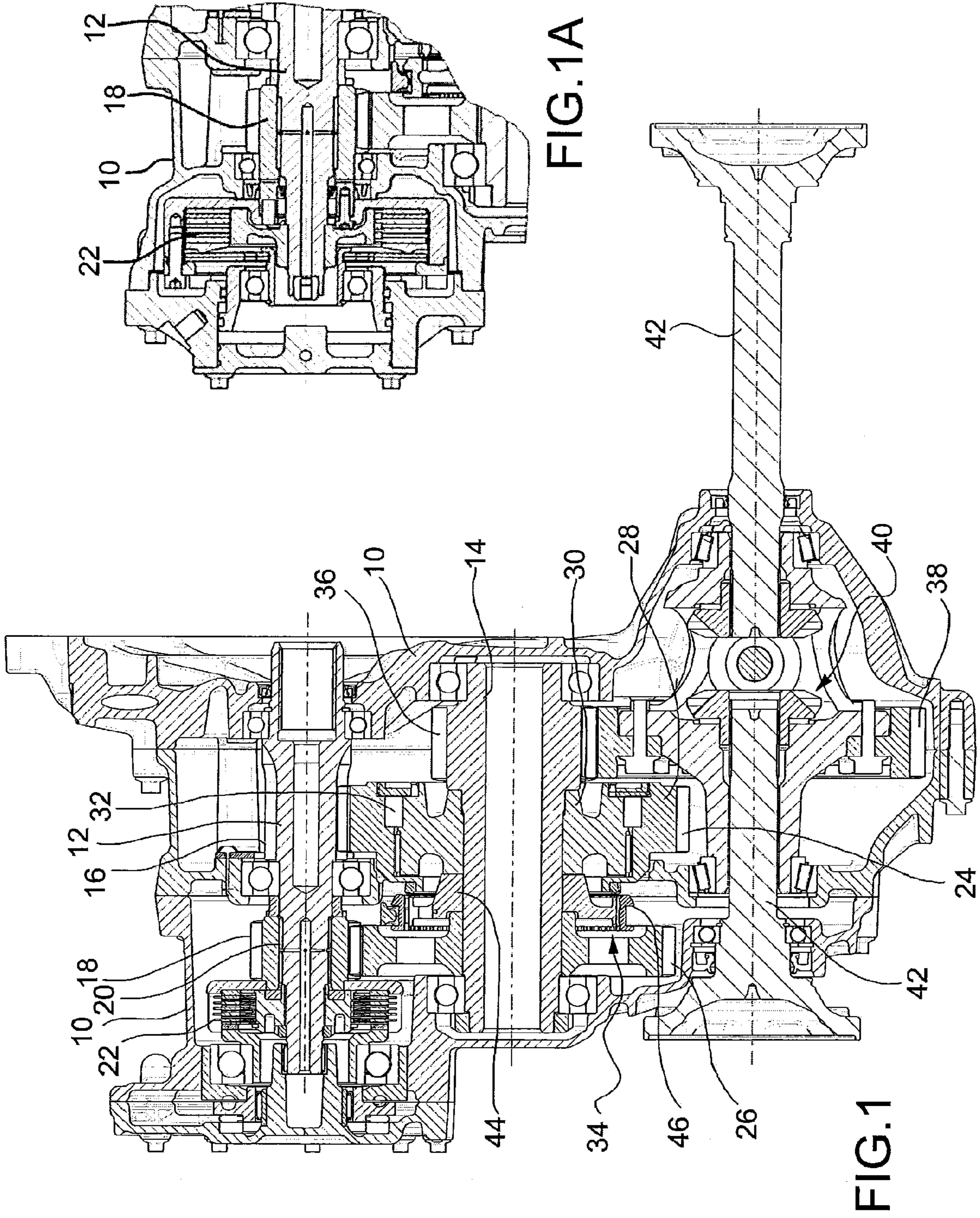


FIG.1A

FIG.1

FIG. 2

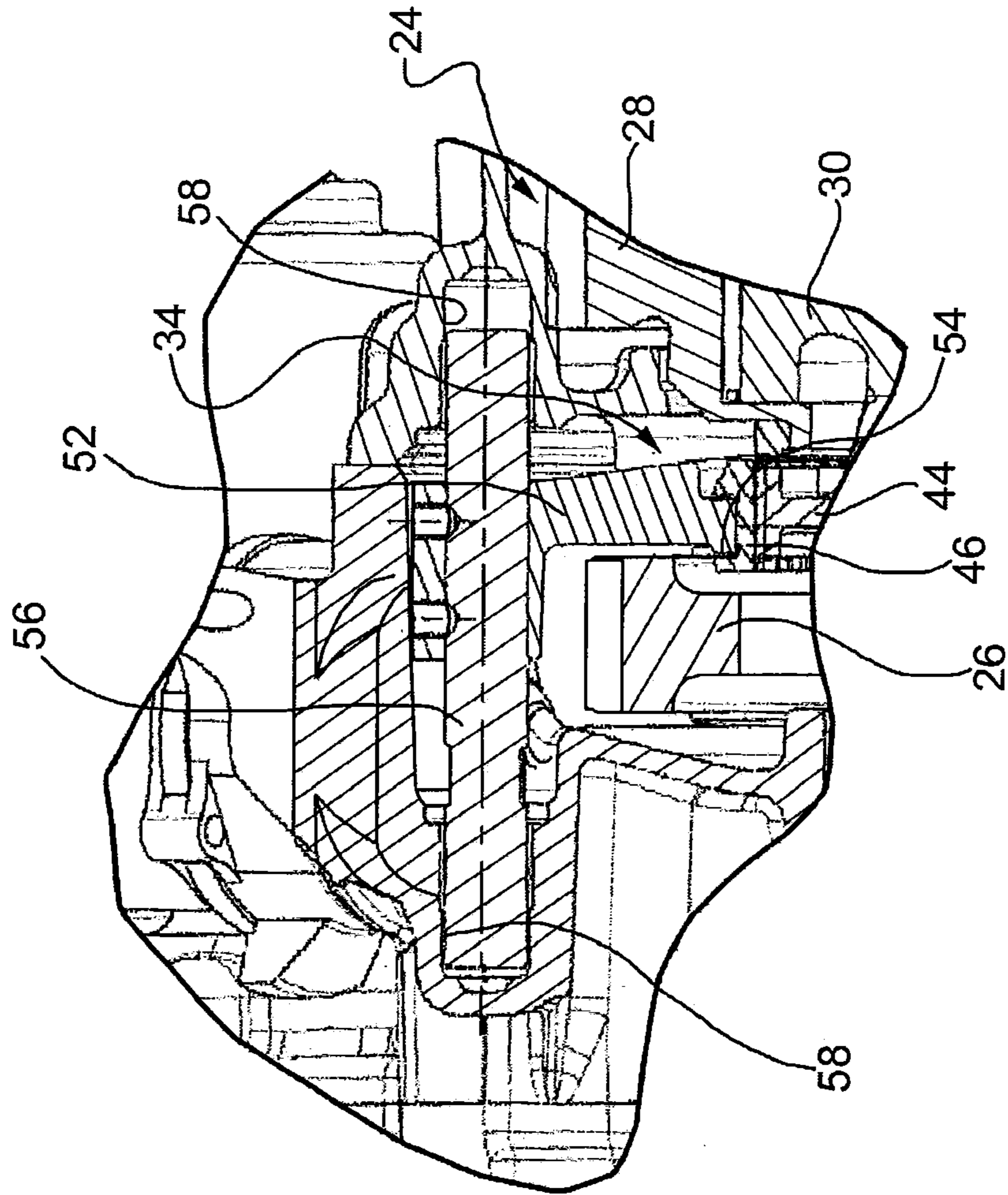


FIG. 3

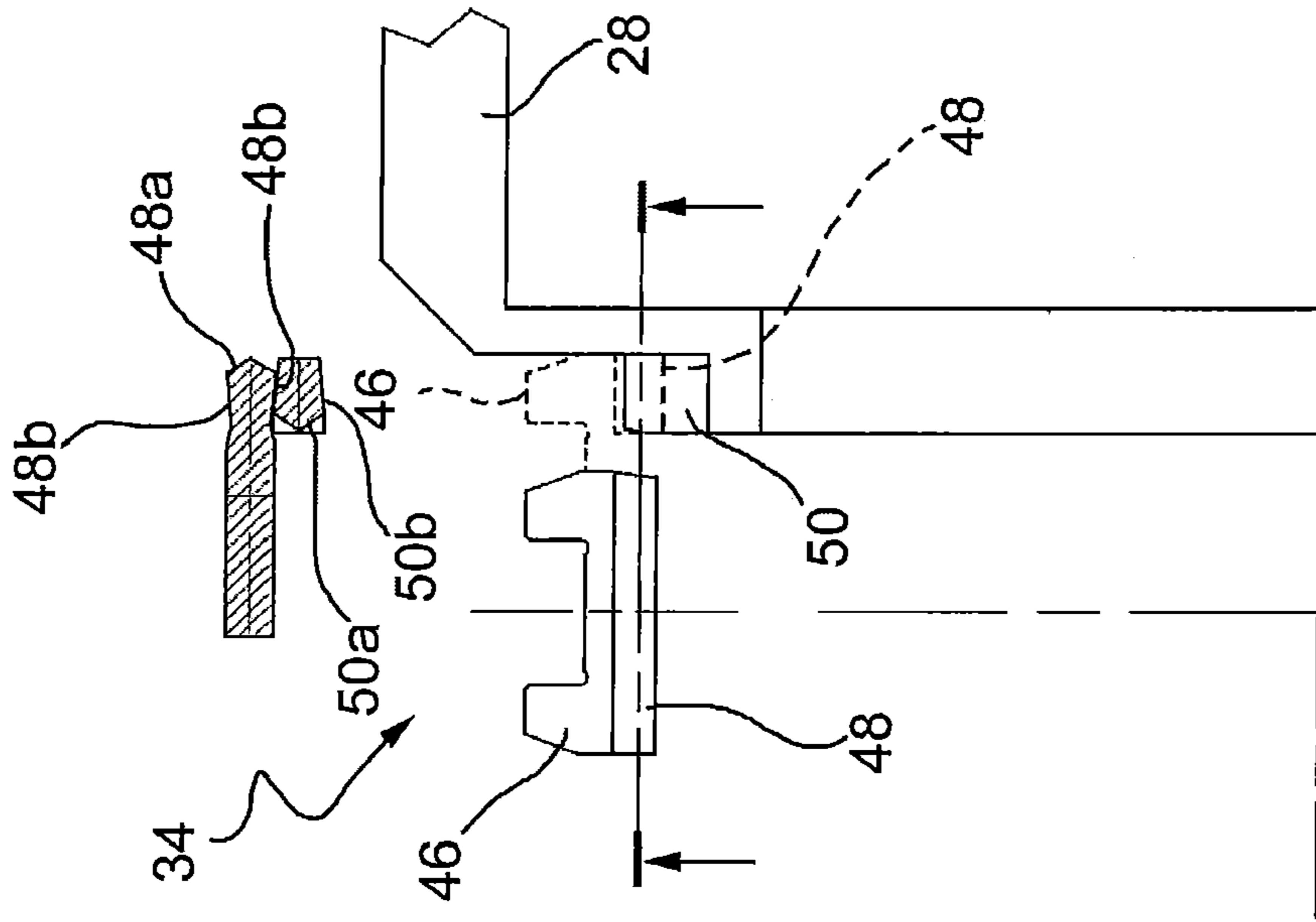




FIG. 4A

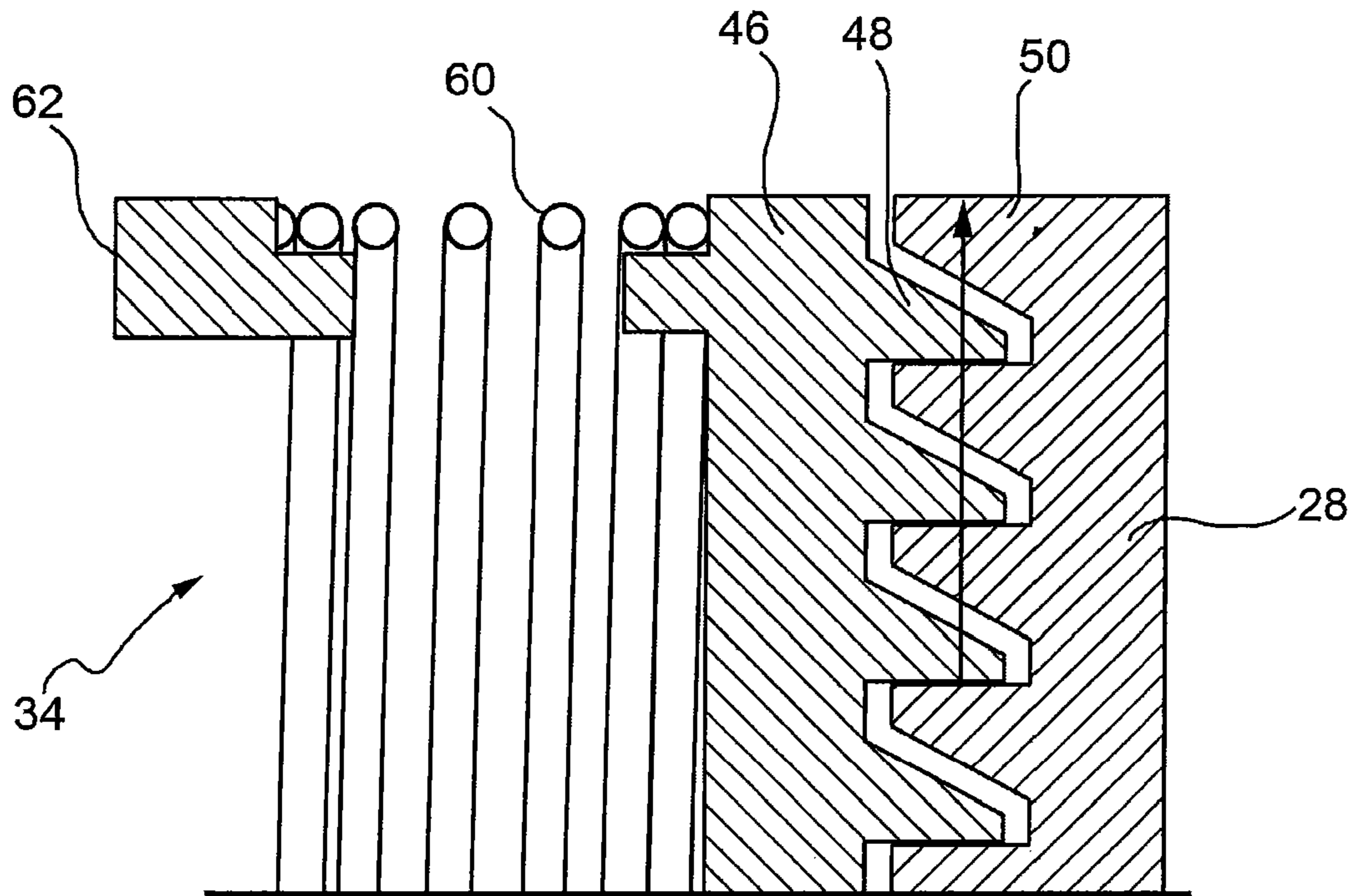
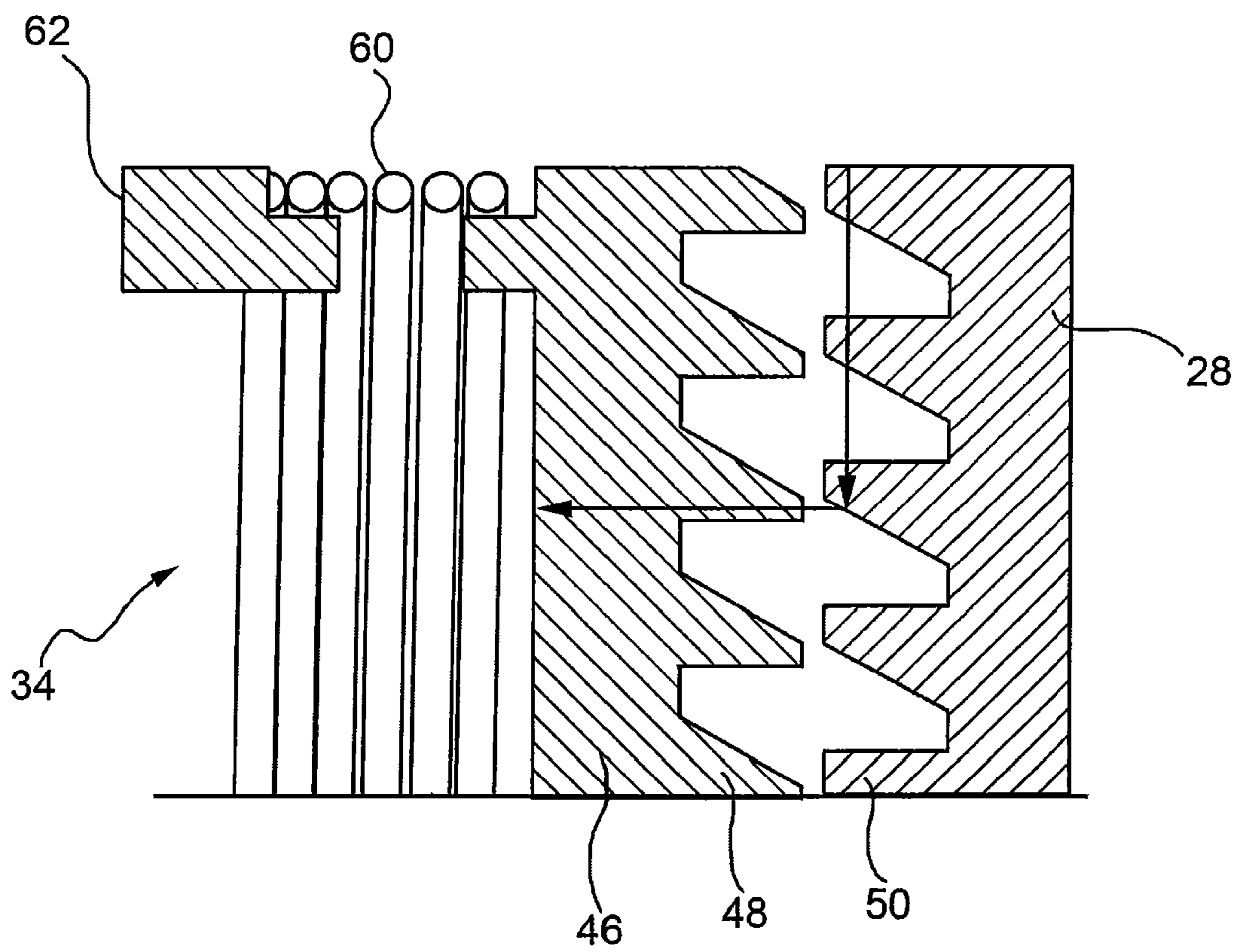


FIG. 4B





## TWO-SPEED TRANSMISSION FOR ELECTRIC VEHICLES

### CROSS REFERENCE TO RELATED APPLICATION

This application claims priority under 35 U.S.C. §119 to Italian Patent Application No. TO2009A000750, filed on Oct. 2, 2009 in the Italian Intellectual Property Office, the disclosure of which application is incorporated herein by reference in its entirety.

### BACKGROUND OF THE INVENTION

The present invention relates to a two-speed transmission intended to be used on electric vehicles. The expression “electric vehicles” is used in the following description and claims to indicate all those vehicles which use an electric machine as prime mover, the electric machine being the only prime mover (it is the case of purely electric vehicles) or being associated to an internal combustion engine (it is the case of hybrid vehicles).

Transmissions having more than one speed, in particular two-speed transmissions, for use on electric vehicles are known and have the advantage, over single-speed transmissions, of allowing the electric machine to work at the optimal number of revolution per minute, that is to say, at the number of revolutions per minute corresponding to the maximum efficiency of the machine, over a wider speed range of the vehicle. This advantage applies both to the traction operating mode, in which the electric machine operates as a motor to generate the power required to move the vehicle, and to the regeneration operating mode, in which the electric machine operates as a generator to convert the kinetic energy of the vehicle, when this latter is decelerating, into electric energy.

In order to avoid interruption in the transmission of the torque (the so-called “torque hole”) when shifting from the first speed (i.e. the low speed) to the second speed (i.e. the high speed) in a two-speed transmission for electric vehicles, it is known from DE4212324 the use of an overrunning clutch associated to the driven gearwheel of the gearing of first speed. More specifically, the two-speed transmission known from this prior art document comprises a primary shaft, a secondary shaft, a gearing of first speed comprising a first driving gearwheel carried by the primary shaft and a first driven gearwheel carried by the secondary shaft and permanently meshing with the first driving gearwheel, a gearing of second speed comprising a second driving gearwheel carried by the primary shaft and a second driven gearwheel carried by the secondary shaft and permanently meshing with the second driving gearwheel, an overrunning clutch associated to the first driven gearwheel, a first coupling device arranged to couple the second driven gearwheel for rotation with the secondary shaft, and a second coupling device arranged to couple the first driven gearwheel, to which the overrunning clutch is associated, for rotation directly with the secondary shaft, so as to allow the transmission of the torque via the gearing of first speed also in the direction from the secondary shaft to the primary shaft. According to such a known solution, both the coupling devices are of the normally open type, that is to say, at rest (no command actively applied to the device) they are in the open condition in which they do not couple the respective gearwheel for rotation with the respective shaft. Moreover, the two coupling devices are controlled

by a single control mechanism which alternatively closes either of the coupling devices.

### SUMMARY OF THE INVENTION

It is an object of the present invention to provide a two-speed transmission for electric vehicles of the above-identified type, which offers better performances and a wider range of operating modes than the prior art discussed above.

This and other objects are fully achieved according to the present invention by virtue of a two-speed transmission for electric vehicles in which a normally closed coupling device is used as a second coupling device (i.e. as coupling device associated to the second speed) and in which the first and second coupling devices are controllable independently of each other, in such a manner that the second coupling device is shiftable between the open condition and the closed condition independently of the open or closed position of the first coupling device.

By virtue of the second coupling device being of the normally closed type, the electric vehicle equipped with a two-speed transmission according to the invention can run in second speed (which is by far the most frequent operating condition for a vehicle of this kind) without having to impart actively any command to the coupling devices of the transmission, which results in less energy consumption. Moreover, by virtue of the two coupling devices being controllable independently of each other, it is possible to close the first coupling device without opening the second coupling device, thereby obtaining a condition in which both the coupling devices are closed and a vehicle parking function is provided.

### BRIEF DESCRIPTION OF THE DRAWINGS

Further characteristics and advantages of the present invention will result from the following detailed description, given purely by way of non-limiting example with reference of the appended drawings, in which:

FIG. 1 is a section view of a two-speed transmission for electric vehicles according to a preferred embodiment of the present invention;

FIG. 1A is a section view in the same section plane as that of FIG. 1, showing in detail a variant of the coupling device associated to the second speed;

FIG. 2 is a section view, in a section plane different from that of FIG. 1, showing on an enlarged scale the control mechanism of the coupling device associated to the second speed;

FIG. 3 is a schematic illustration of the engagement teeth of the sliding sleeve of the coupling device associated to the first speed and of the idle gearwheel of the gearing providing the first speed; and

FIGS. 4A and 4B are schematic illustrations of a variant of the engagement teeth of the sliding sleeve of the coupling device associated to the first speed and of the idle gearwheel of the gearing providing the first speed, in the engaged (or closed) condition and in the disengaged (or open) condition of this coupling device, respectively.

### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

With reference first to FIG. 1, a two-speed transmission for electric vehicles according to a preferred embodiment of the present invention comprises a casing or housing 10, a primary shaft 12 supported for rotation by the casing 10, and a sec-



ondary shaft **14** supported for rotation by the casing **10** and arranged parallel to the primary shaft **12**.

The primary shaft **12** carries a first driving gearwheel **16** for the first speed (i.e. the low speed) and a second driving gearwheel **18** for the second speed (i.e. the high speed). In the illustrated embodiment, the first driving gearwheel **16** is fixed, that is to say, rigidly connected for rotation with the respective shaft (primary shaft **12**), and more particularly it is made in a single piece with the primary shaft **12**, whereas the second driving gearwheel **18** is idle, that is to say, free to rotate relative to the primary shaft **12**, on which it is supported for example by means of needle bearing(s) **20**. The primary shaft **12** is also provided with a first coupling device **22** which is made for example as a friction clutch and is associated to the second driving gearwheel **18**. The first coupling device **22** is of the normally open type and therefore at rest it keeps the second driving gearwheel **18** connected for rotation with the primary shaft **12**, whereas when it is actively controlled (for instance mechanically, hydraulically or electrically) it disconnects the second driving gearwheel **18** for rotation from the primary shaft **12**. In the embodiment illustrated in FIG. 1, the coupling device **22** is a wet multi-disc friction clutch, but it might naturally be a friction clutch of different type as well, for example a dry single-disc or multi-disc friction clutch, as shown in FIG. 1A.

The secondary shaft **14** carries a first driven gearwheel **24** for the first speed and a second driven gearwheel **26** for the second speed.

The first driven gearwheel **24** comprises an idle ring gear **28** permanently meshing with the first driving gearwheel **16**, a hub **30** rigidly connected for rotation with the secondary shaft **14** (in the illustrated example the hub **30** is made as a separate piece with respect to the secondary shaft **14** and is firmly secured thereto, but might naturally be made in a single piece with the secondary shaft **14** as well) and an overrunning clutch **32** (also known as freewheel), which is interposed between the ring gear **28** and the hub **30** of the first driven gearwheel **24** and is arranged to couple these two components of the first driven gearwheel for rotation with each other when the primary shaft **12** transmits torque to the secondary shaft **14** (traction phase) and until the angular velocity of the secondary shaft **14** (and, hence of the hub **30**) is lower than or equal to the angular velocity of the primary shaft **12** divided by the transmission ratio of first speed. The first driven gearwheel **24**, or better its ring gear **28**, has been defined above as "idle" to mean that this ring gear is not rigidly connected for rotation with the respective shaft (secondary shaft **14**), unlike the other gearwheel **16** of the gearing of first speed, but in certain operating conditions (those where the overrunning clutch **32** disconnects the ring gear **28** for rotation from the hub **30**) it is free to rotate relative to the shaft **14**.

In the illustrated embodiment, the second driven gearwheel **26** is made as a fixed wheel, that is to say, it is rigidly connected for rotation with the secondary shaft **14**, and permanently meshes with the second driving gearwheel **18**. The secondary shaft **14** carries also a second coupling device **34** arranged to couple the ring gear **28** of the first driven gearwheel **24** for rotation with the secondary shaft **14**. The coupling device **34** may be made either as a normally closed coupling device, in which case it keeps at rest the ring gear **28** of the first driven gearwheel **24** connected for rotation with the secondary shaft **14**, or as a normally open coupling device, in which case it keeps at rest the ring gear **28** of the first driven gearwheel **24** free to rotate relative to the secondary shaft **14**. The secondary shaft **14** carries also a final reduction pinion **36**, which in the illustrated embodiment is made in a single piece with the secondary shaft **14**. The final reduction pinion

**36** permanently meshes with a ring gear **38** of a differential **40** interposed between a pair of axle shafts **42** on which the driving wheels (not shown) are mounted.

With reference also to FIG. 2, the second coupling device **34** comprises a hub **44** rigidly connected for rotation with the secondary shaft **14** and a sliding sleeve **46** connected to the hub **44** by means of a splined profile so as to be rigidly connected for rotation with the hub, but free to translate axially relative thereto. As can be better seen in FIG. 3, at the end facing the first driven gearwheel **24**, the splined profile of the sliding sleeve **46** forms first engagement teeth **48** arranged to mesh with second engagement teeth **50** formed by the ring gear **28** of the first driven gearwheel **24**. In the example illustrated in FIG. 3, the engagement teeth **48** and **50** have in plan view a V-shaped front end (indicated **48a** and **50a** for the teeth **48** and the teeth **50**, respectively) and a pair of inclined flanks (indicated **48b** and **50b** for the teeth **48** and the teeth **50**, respectively) diverging outwards. In order to cause the sliding sleeve **46** to move between a disengagement position (shown in solid line in FIG. 3), in which the engagement teeth **48** and **50** are disengaged, and an engagement position (shown in broken line in FIG. 3), in which the engagement teeth **48** and **50** mesh with each other, whereby the ring gear **28** of the first driven gearwheel **24** is connected for rotation with the secondary shaft **14**, the transmission is further provided with a control mechanism (shown in detail in FIG. 2), which in the illustrated embodiment comprises a sliding actuating fork **52** which engages in a circumferential groove **54** of the sliding sleeve **46**. In the illustrated embodiment, the actuating fork is secured to a sliding rod **56** guided at the opposite ends within respective coaxial guide cavities **58** formed by the casing **10**. The translational movement of the sliding rod **56** is controlled by an actuator device (not shown), which may be of hydraulic or electric type. However, the mechanism for actuating the sliding sleeve **46** of the second coupling device **34** may naturally be of any other type.

The operation of the two-speed transmission for electric vehicles illustrated above in structural terms will be described now.

With the friction clutch **22** kept open (by command imparted by the respective control device), as soon as the electric motor starts to run, the driving torque is transmitted from the primary shaft **12** to the secondary shaft **14** via the first driving gearwheel **16** and the first drive gearwheel **24** forming the gearing of first speed, the ring gear **28** of the first driven gearwheel **24** being connected for rotation with the hub **30**, and therefore to the secondary shaft **14**, by means of the overrunning clutch **32**. Preferably, as soon as the vehicle starts to move, the coupling device **34** is closed (in case of normally open device) or kept closed (in case of normally closed device) to couple the ring gear **28** of the first driven gearwheel **24** for rotation with the secondary shaft **14**. In this way, even though the torque is still transmitted from the primary shaft **12** to the secondary shaft **14** preferably via the overrunning clutch **32**, due to the fact that the plays inside the overrunning clutch **32** are suitably chosen so as to be smaller than the plays between the engagement teeth **48** and **50** of the sliding sleeve **46** and of the ring gear **28**, the sliding sleeve **46** is already in the engagement position and therefore the transmission is immediately able to operate also in regeneration mode with the first speed engaged. In fact, in case of braking (or, more generally, in case of deceleration) or downhill, the torque is transmitted from the driving wheels to the electric machine flowing in the order via the secondary shaft **14**, the hub **44** and the sliding sleeve **46** of the coupling device **34**, the ring gear **28**, the first driving gearwheel **16** and the primary shaft **12**, the electric machine operating accordingly as a



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generator to charge the batteries of the vehicle. When running in first speed (that is to say, in the illustrated embodiment, with the friction clutch **22** open), the second driving gearwheel **18** rotates idly both in traction mode and in regeneration mode, as it is driven for rotation by the second driven gearwheel **26** with which it permanently meshes.

In order to allow to shift from the first speed to the second speed, the coupling device **34** is opened, thus disengaging the engagement teeth **48** of the sliding sleeve **46** from the engagement teeth **50** of the ring gear **28** and hence causing the torque to be transmitted from the primary shaft **12** to the secondary shaft **14** via the overrunning clutch **32**. The coupling device **22** is then brought in its normal closed condition, whereby the second driving gearwheel **18** is connected for rotation with the primary shaft **12**. In this way, as soon as the angular velocity of the ring gear **28** becomes lower than the angular velocity of the hub **30**, i.e. of the secondary shaft **14**, the overrunning clutch **32** is “by-passed” and therefore the driving torque is transmitted from the primary shaft **12** to the secondary shaft **14** via the driving gearwheel **18** and the driven gearwheel **26** of the gearing of second speed. The use of the overrunning clutch **32** for transmission of the torque via the gearing of first speed, which clutch works in parallel to the gearing of second speed when the second driving gearwheel **18** is coupled for rotation with the primary shaft **12** once the coupling device **22** is closed, makes it possible to shift from the first to the second speed without interruptions in the transmission of the torque, that is to say, in the so-called “power-shift” mode. With the second speed engaged, the operation in regeneration mode is enabled by the fact that the driving gearwheel **18** and the driven gearwheel **26** of the gearing of second speed permanently mesh with each other.

FIGS. **4A** and **4B**, where parts and elements identical or corresponding to those of the preceding figures are given the same reference numerals, show an alternative embodiment of the coupling device associated to the first speed, according to which the engagement teeth of the sliding sleeve and of the ring gear of the first driven gearwheel are made as saw-toothed teeth. More specifically, the coupling device **34** comprises a sliding sleeve **46**, which is connected for rotation with the secondary shaft **14** and is axially slidable between an engagement position (FIG. **4A**), in which the engagement teeth **48** of the sliding sleeve **46** mesh with the engagement teeth **50** of the ring gear **28**, and a disengagement position (FIG. **4B**), in which the engagement teeth **48** and **50** are disengaged from each other, and a spring **60** interposed between a stationary ring **62** and the sliding sleeve **46** to urge axially this latter towards the ring gear **28**. The inclined flanks of the engagement teeth **48** and **50** are oriented in such a manner that in the traction operating mode with the first speed engaged, in which mode the torque flows from the ring gear **28** to the sliding sleeve **46**, the axial component of the force exchanged between the engagement teeth **48** and **50** tends to move the sliding sleeve **46** away from the ring gear **28** against the resilient force of the spring **60**, thereby causing the engagement teeth **48** and **50** to disengage from each other (FIG. **4B**). In this operating mode, the sliding sleeve **46** is kept in the disengagement position either electromagnetically or hydraulically or, again, mechanically by means of an actuating device acting directly on the sliding sleeve or indirectly through a rod and fork mechanism such as the one described above with reference to FIG. **2**. The torque is therefore transmitted from the primary shaft **12** to the secondary shaft **14** via the overrunning clutch **32**.

As soon as the traction request ceases, the sliding sleeve **46** is unlocked and, being no more opposed by the axial force applied by the engagement teeth **50** of the ring gear **28**, shifts

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from the disengagement position to the engagement position under the action of the spring **60**. In that condition, the torque is transmitted from the secondary shaft **14** to the primary shaft **12** due to the engagement between the engagement teeth **48** and **50** of the sliding sleeve **46** and of the ring gear **28**, and more in particular between the flat faces of those teeth (FIG. **4A**).

In the traction operating mode with the second speed engaged, the overrunning clutch is “by-passed” and, like the case where the first speed is engaged, the axial component of the force applied by the inclined flanks of the engagement teeth **50** of the ring gear **28** on the inclined flanks of the engagement teeth **48** of the sliding sleeve **46** causes this latter to shift from the engagement position to the disengagement position.

According to a further variant of embodiment, not illustrated, the spring may be replaced by a special actuating device (for example of electro-magnetic, hydraulic or mechanical type) arranged to control the movement of the sliding sleeve from the disengagement position to the engagement position, while a locking device is still provided and may also be for example of electromagnetic, hydraulic or mechanical type, the locking device being arranged to keep the sliding sleeve in the disengagement position during operation in traction mode.

Advantageously, in a transmission according to the invention the parking function can be provided by using the sliding sleeve of the coupling device associated to the first speed as parking device. When the vehicle is stationary, in fact, since the coupling device associated to the second speed is of normally closed type, both the gearwheels of the gearing of second speed are connected for rotation to the respective shaft, and therefore, if the coupling device associated to the first speed is also brought or kept in the closed condition (which is allowed by the fact that this coupling device can be in the open or closed condition independently of the open or closed condition of the other coupling device), also the first speed is simultaneously engaged and the transmission is therefore locked.

As already mentioned in the introductory part of the description, a further advantage of the transmission according to the invention is that the use of a normally closed coupling device as the coupling device associated to the second speed allows to drive in second speed (which is by far the most frequent operating condition of the vehicle) without imparting any command to that coupling device, which results in the energy consumption of the vehicle being brought to a minimum level.

Naturally, the principle of the invention remaining unchanged, the embodiments and manufacturing details may be widely varied from those described and illustrated purely by way of non-limiting example, without thereby departing from the scope of the invention as defined in the attached claims.

For example, as discussed above, FIG. **1** illustrates a transmission in which the driven gearwheel **24** of the first speed and the driving gearwheel **18** of the second speed are idle. The overrunning clutch **32** and the second coupling device **34** are therefore associated with the driven gearwheel **24**, while the first coupling device **22** is associated with the driving gearwheel **18**. The transmission may also be produced with the driving gearwheel **16** being the idle wheel of the gearing of first speed, in which case the overrunning clutch **32** will be associated to the driving gearwheel **16**, instead of the driven gearwheel **24**, of first speed and/or with the driven gearwheel **26** being the idle wheel of the gearing of second speed, in which case the coupling device **22** associated to the second



speed will act on the driven gearwheel **26**, instead of the driving gearwheel **24**, of the gearing of second speed.

Moreover, even though the transmission illustrated in the drawings is arranged transversely, that is to say, with the primary and secondary shafts oriented transversely relative to the running direction of the vehicle, and hence parallel to the axes of the wheels, the present invention also encompasses a longitudinal arrangement of the transmission, that is to say, with the primary and secondary shafts oriented parallel to the running direction of the vehicle, and hence transversely relative to the axes of the wheels.

What is claimed is:

**1.** A two-speed transmission for electric vehicles provided with an electric machine able to operate alternatively as a motor according to a traction operating mode or as a generator according to a regeneration operating mode, the transmission comprising:

a primary shaft;

a secondary shaft;

a gearing of first speed, or low speed, comprising a first driving gearwheel carried by the primary shaft and a first driven gearwheel carried by the secondary shaft and permanently meshing with the first driving gearwheel;

a gearing of second speed, or high speed, comprising a second driving gearwheel carried by the primary shaft and a second driven gearwheel carried by the secondary shaft and permanently meshing with the second driving gearwheel;

an overrunning clutch associated to said first driven gearwheel to allow the transmission of the torque via the gearing of first speed only in the direction from the primary shaft to the secondary shaft;

a first coupling device selectively coupling said second driving gearwheel for rotation with the primary shaft, said first coupling device being shiftable between an open condition and a closed condition; and

a second coupling device selectively coupling said first driven gearwheel, namely the gearwheel to which the overrunning clutch is associated, for rotation directly with the secondary shaft, said second coupling device being shiftable between an open condition and a closed condition;

characterized in that said first coupling device is normally closed and is shiftable between the open condition and the closed condition independently of the open or closed condition of said second coupling device.

**2.** The transmission according to claim **1**, wherein said second coupling device is normally open.

**3.** The transmission according to claim **1**, wherein said first driving gearwheel is permanently connected for rotation with the primary shaft, whereas said first driven gearwheel is connectable for rotation with the secondary shaft via the overrunning clutch, and wherein said second driven gearwheel is permanently connected for rotation with the secondary shaft, whereas said second driving gearwheel is idly mounted on the primary shaft and is connectable for rotation with this latter by means of said first coupling device.

**4.** The transmission according to claim **1**, wherein said first driven gearwheel comprises a ring gear permanently meshing with said first driving gearwheel, and wherein the overrunning clutch is radially interposed between the ring gear and the secondary shaft.

**5.** The transmission according to claim **1**, wherein said second coupling device comprises a sliding sleeve provided with first engagement teeth arranged to mesh with second engagement teeth of said first driven gearwheel, the sliding sleeve being connected for rotation with the secondary shaft and being axially slidable between a disengagement position, in which said first and second engagement teeth are disengaged from each other, and an engagement position, in which said first and second engagement teeth mesh with each other, whereby said first driven gearwheel is connected for rotation with the secondary shaft.

**6.** The transmission according to claim **5**, wherein said second coupling device further comprises an actuating mechanism arranged to cause the sliding sleeve to move between said engagement and disengagement positions.

**7.** The transmission according to claim **6**, wherein said first and second engagement teeth are saw-toothed teeth made in such a manner that, in traction operating mode with the first speed engaged, the sliding sleeve is moved into the disengagement position by the axial component of the force exchanged between said first and second engagement teeth.

**8.** The transmission according to claim **7**, wherein the actuating mechanism comprises at least one spring tending to urge the sliding sleeve towards the engagement position or the disengagement position.

**9.** The transmission according to claim **1**, wherein said first coupling device is a friction clutch.

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